

# Ion thermal decoupling in shock-driven implosions on OMEGA

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Tuesday, April 5, 3:30 pm  
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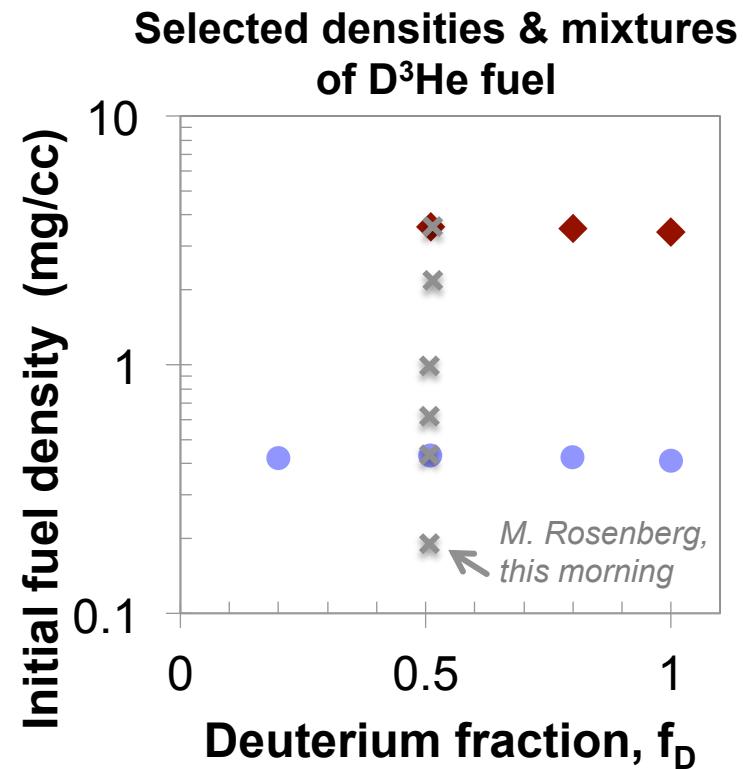
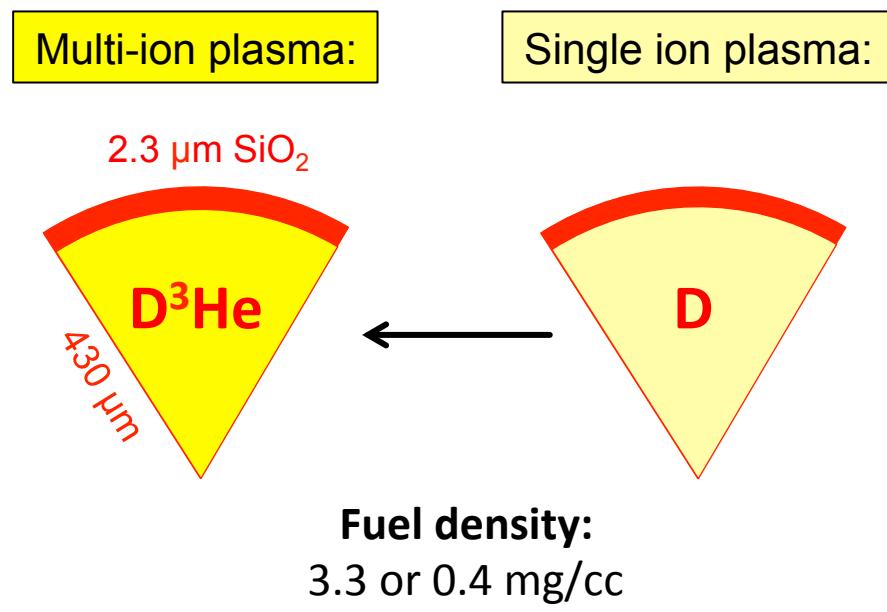


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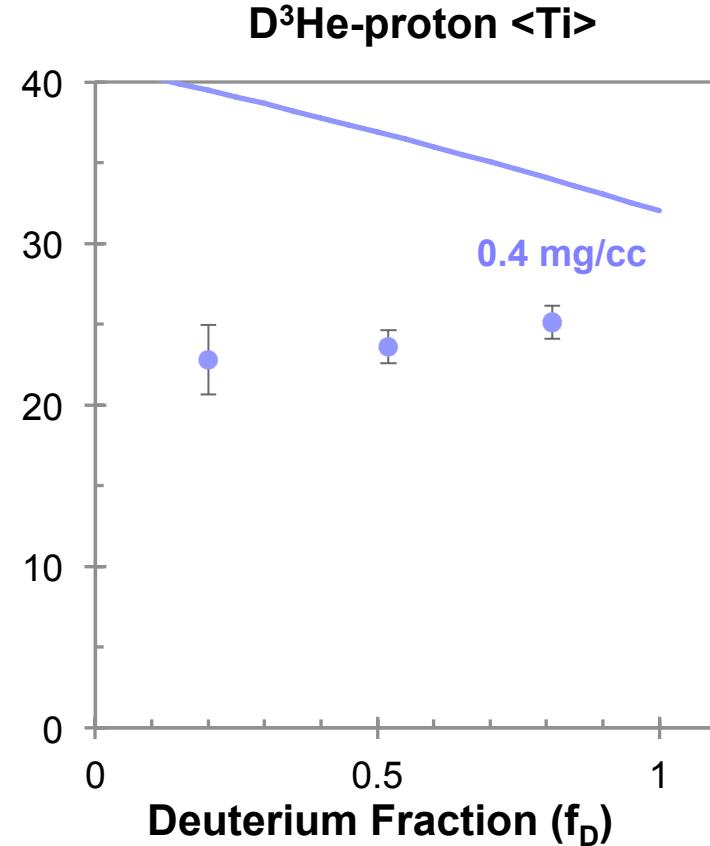
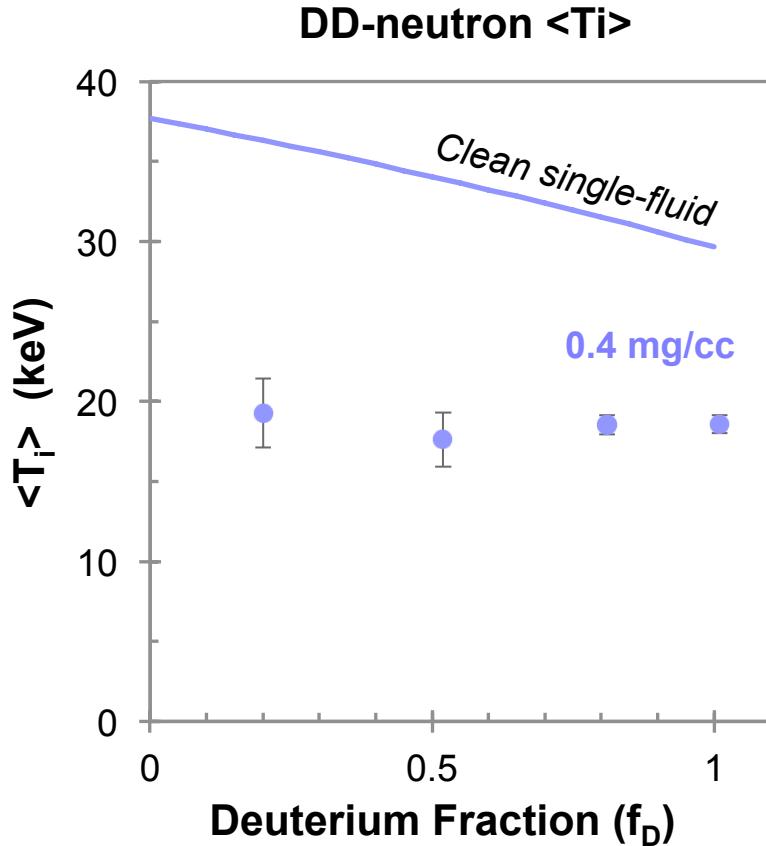
# The importance of multiple-ion species kinetic effects was studied using a D:<sup>3</sup>He fuel ratio scan in shock-driven implosions



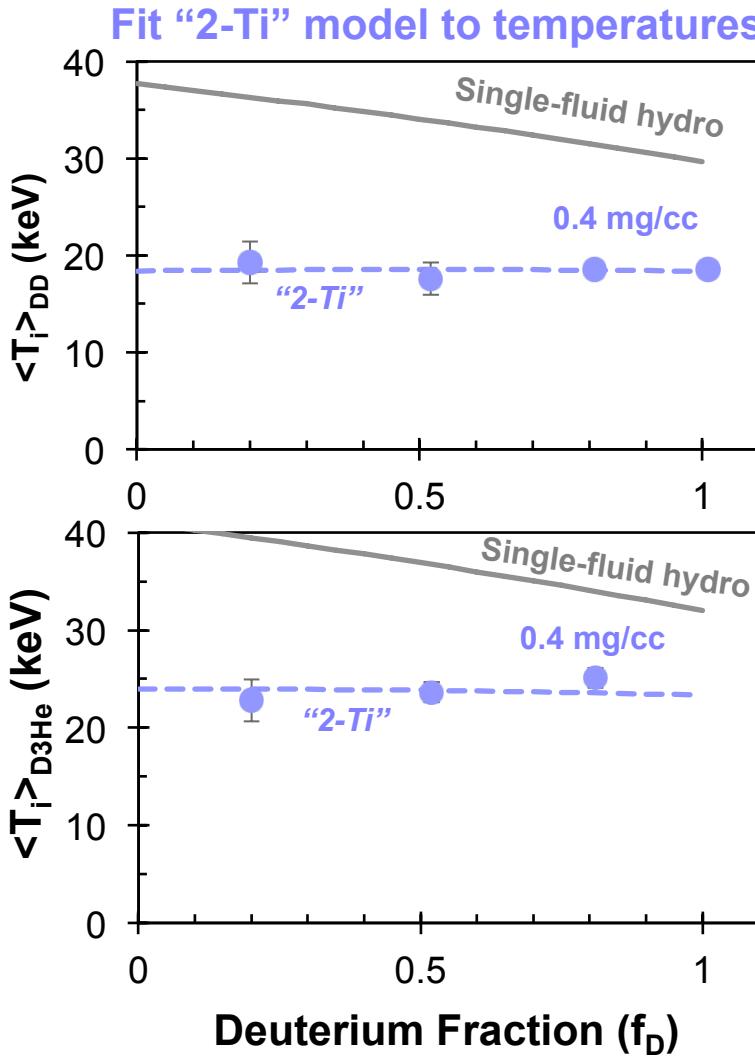
$$f_D = \frac{n_D}{n_D + n^{^3\!He}}$$

Rinderknecht, et al., PRL 114, 025001 (2015)

In low-density implosions, ion temperatures exhibit unexpected trends:  $\langle T_i \rangle$  is *anomalously constant* with  $f_D$

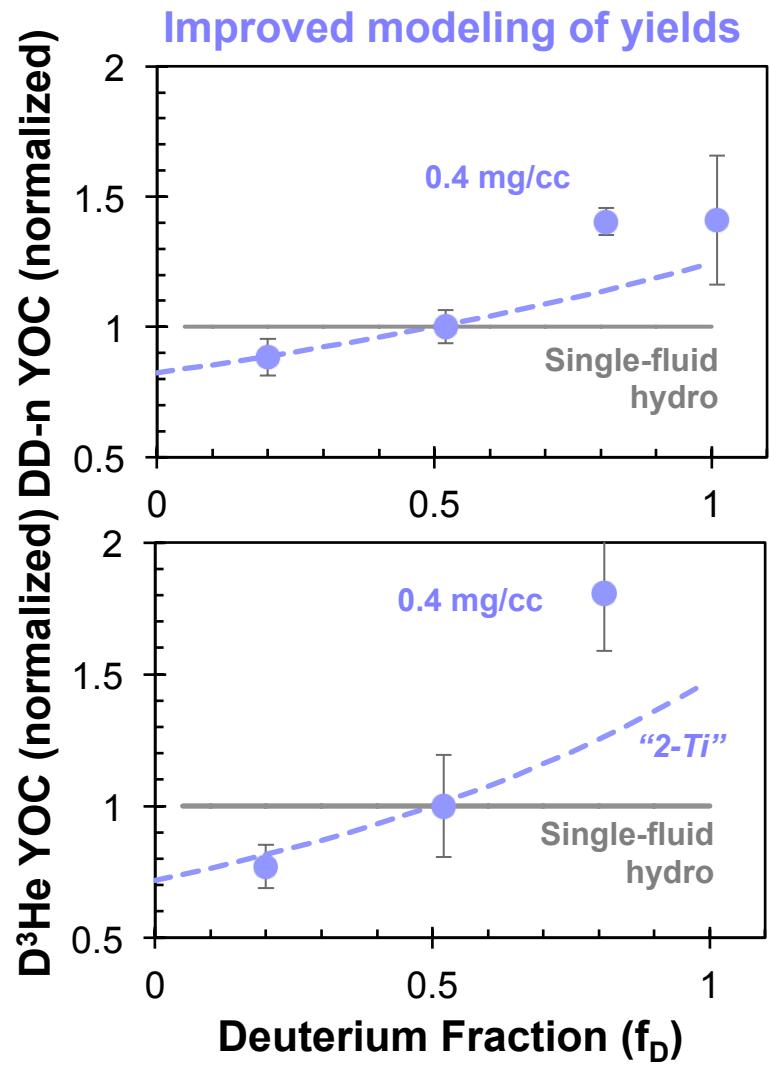
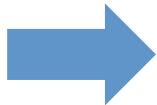
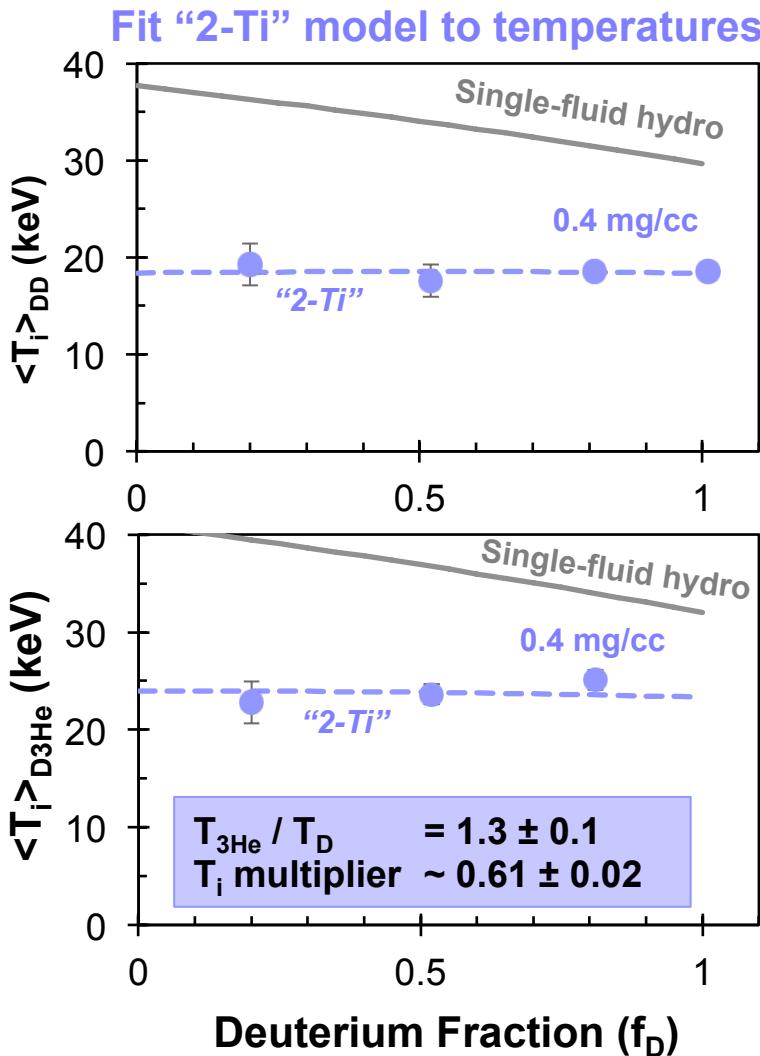


For low gas-density implosions, an empirical thermal decoupling model ( $T_{^3\text{He}} \neq T_D$ ) was fit to the temperature data;



$$\begin{aligned} T_{^3\text{He}} / T_D &= 1.3 \pm 0.1 \\ T_i \text{ multiplier} &\sim 0.61 \pm 0.02 \end{aligned}$$

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# Does thermal decoupling make sense for these experiments?

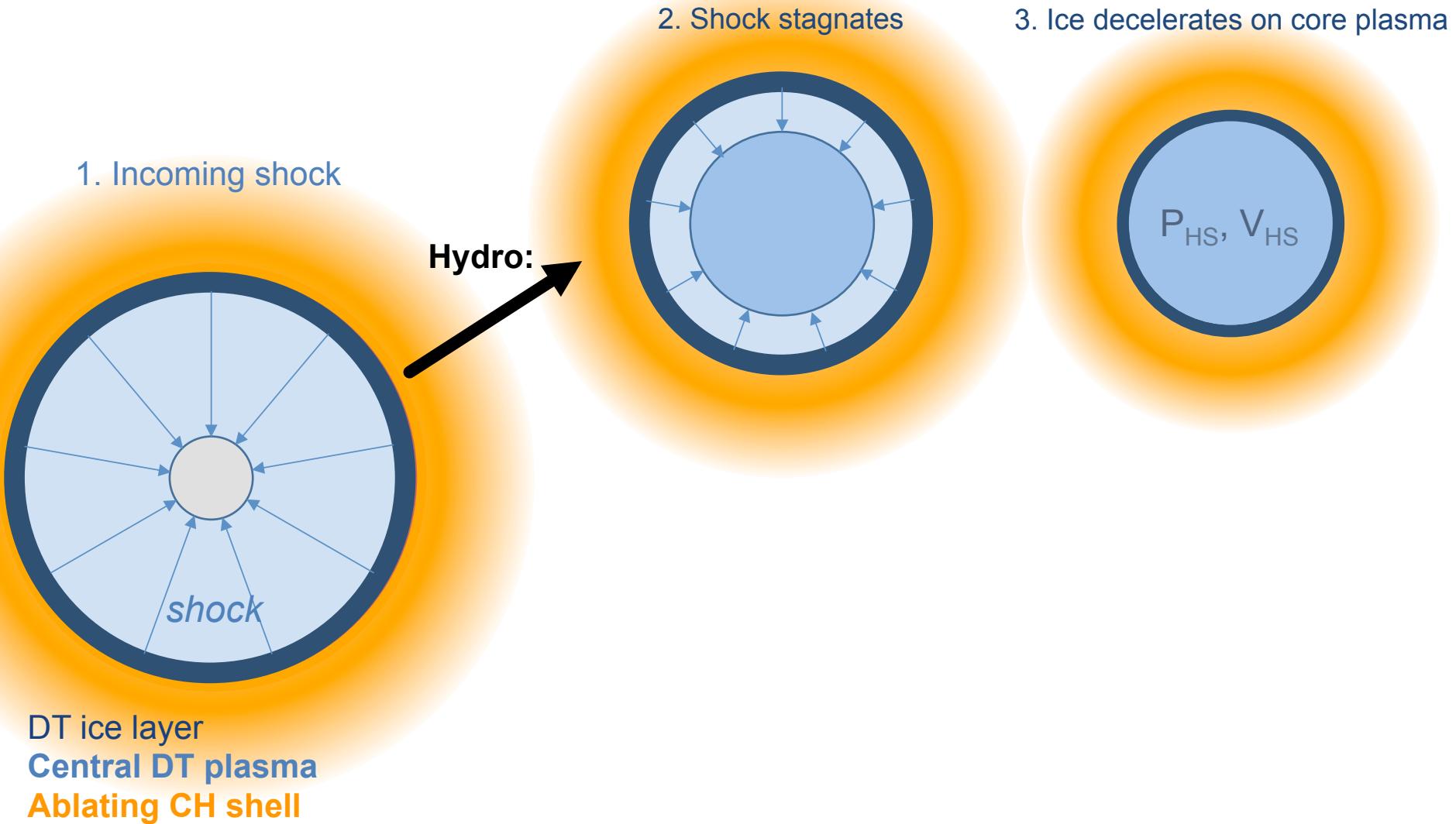
$$T_{i,\text{shock}} \propto m_i v_{\text{shock}}^2 \rightarrow \frac{T_{^3\text{He}}}{T_D} \approx 1.5 \quad \checkmark$$

Ion-ion equilibration times at  $f_D = 0.5$ :

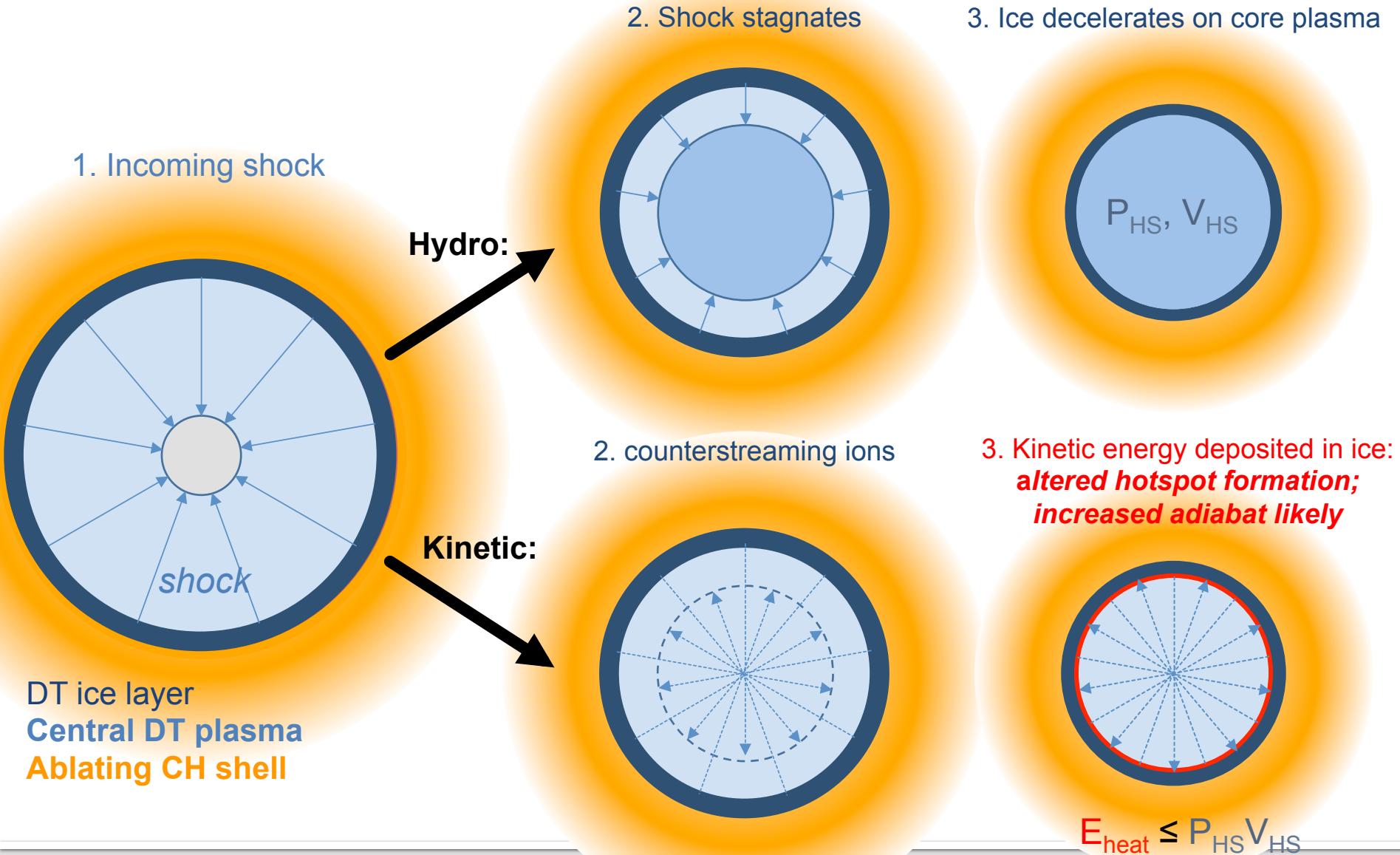
$$\begin{array}{lll} T_{D/3\text{He}} & \sim 330 \text{ ps} \\ T_{D/D} & \sim 980 \text{ ps} & > \tau_{\text{burn}} = 180 \text{ ps} \end{array} \quad \checkmark$$

... but *thermalization time* is on the order of *collision time* –  
this finding implies the species are not self-equilibrated!

# Thought experiment: the hydrodynamic picture assumes shock stagnation prior to the deceleration phase...



# Thought experiment: a *fully kinetic* (i.e. collisionless) low-density DT plasma inside the DT ice layer could alter deceleration phase



## Summary:

# Thermal decoupling of ion species was observed in nuclear data from low-density implosions on OMEGA

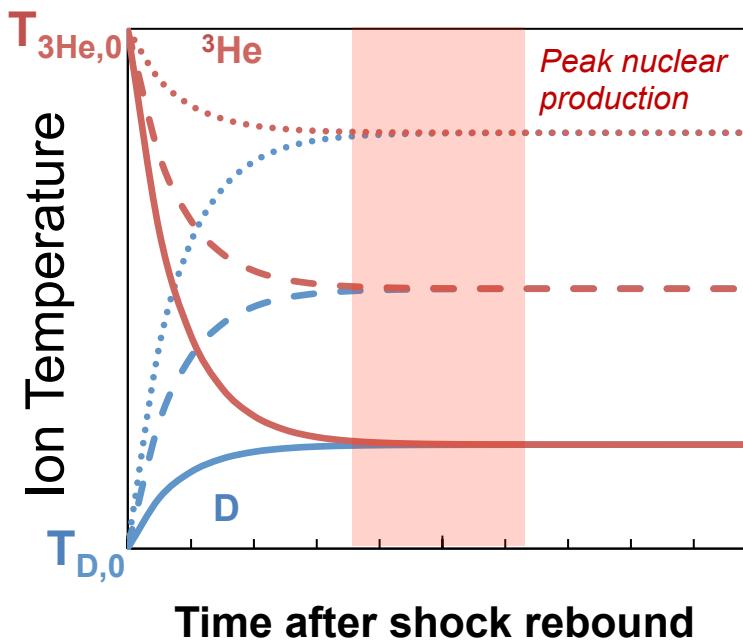
- Low-density implosions (0.4 mg/cc) exhibited anomalously constant  $\langle T_i \rangle$  as deuterium fraction was changed
  - This is a signature that D and  $^3\text{He}$  were not equilibrated during fusion
- A model with  $T_{^3\text{He}}/T_D > 1$  better reproduces both the observed  $\langle T_i \rangle$  and yields
- Thermal decoupling implies non-thermalized ion populations, with potential impact on energy balance in the core of the ignition design prior to deceleration phase

# Appendix – Ion thermal decoupling

Since the shock heats the ion species differentially,  
equilibration rate affects the burn-averaged ion temperature

Rapid equilibration (fluid):

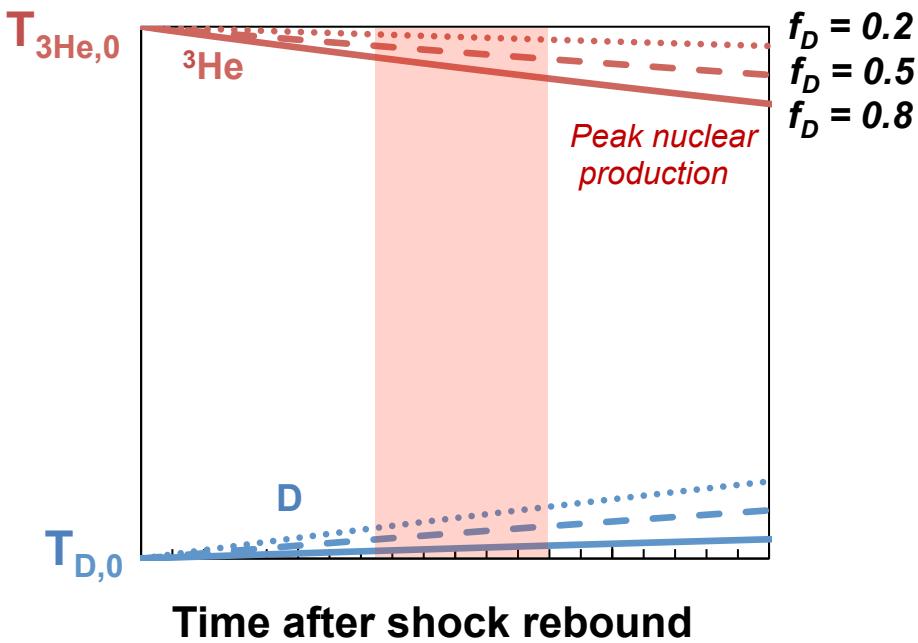
$$T_{\text{eq}} \ll T_{\text{burn}}$$



$$\langle T_i \rangle \sim (3 - f_D)$$

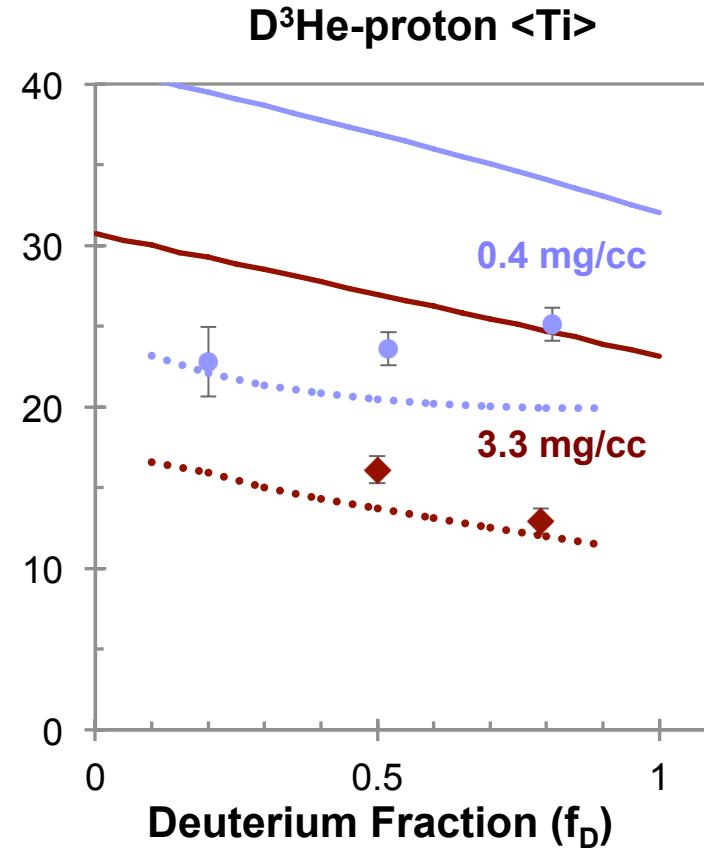
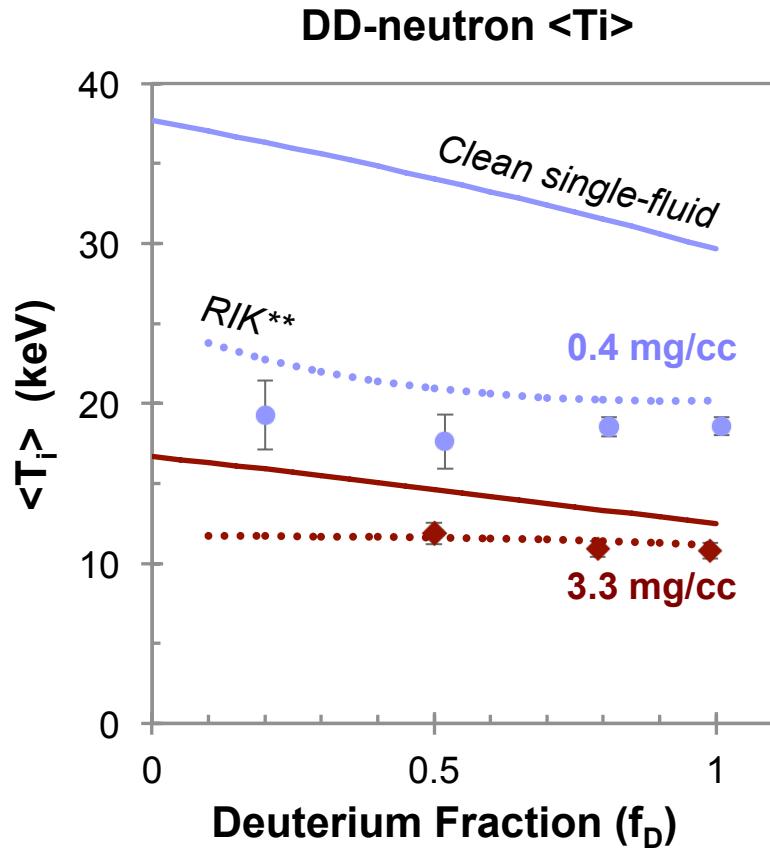
Slow equilibration (kinetic):

$$T_{\text{eq}} \gg T_{\text{burn}}$$



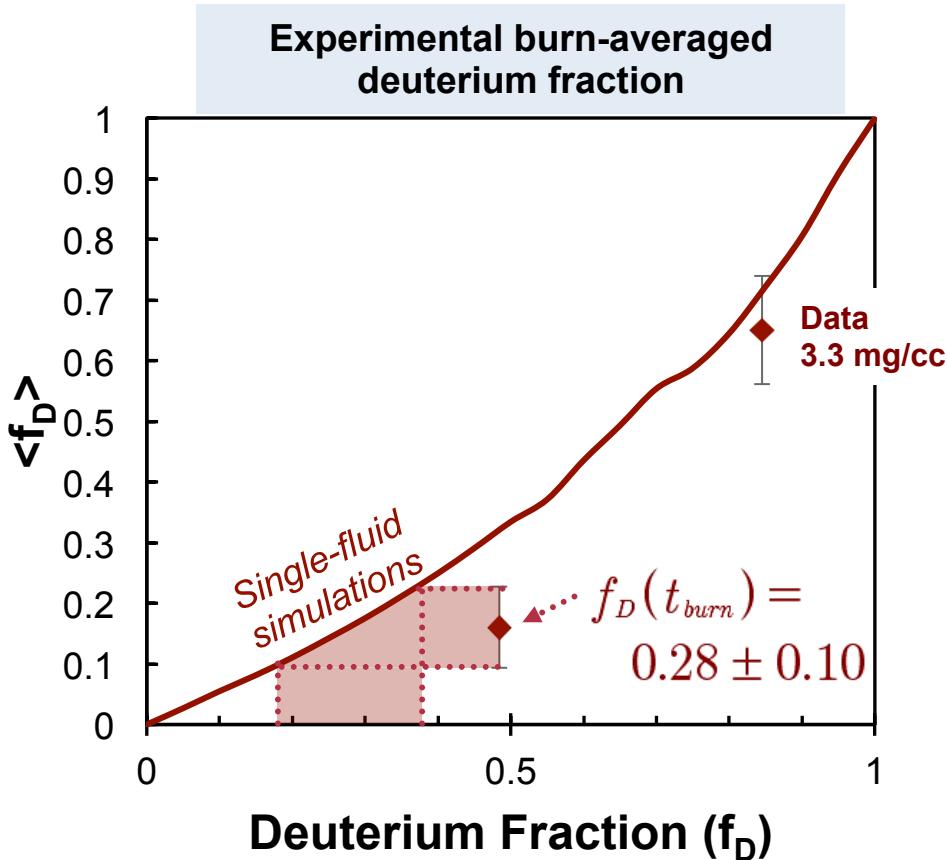
$$\langle T_i \rangle \sim \text{constant} \quad (\text{as observed})$$

In low-density implosions, ion temperatures exhibit unexpected trends:  $\langle T_i \rangle$  is *anomalously constant* with  $f_D$

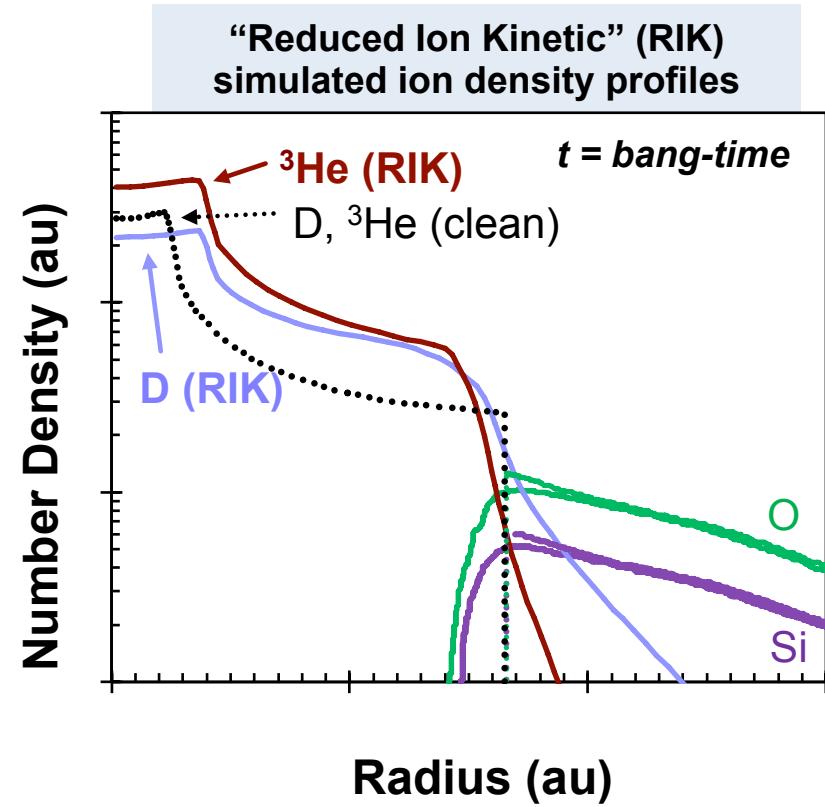


\*\*Single-fluid + "Reduced Ion Kinetic" models incl. diffusion; see N. Hoffman tomorrow

The “burn-averaged deuterium fraction” was calculated from nuclear observables, confirming simulated diffusive species separation



This is the first direct evidence of ion species separation in an ICF implosion



$$f_D(t_0) = 50\% \rightarrow f_D(t_{burn}) = 33\%$$

Simulations by Nels Hoffman, LANL  
(see presentation tomorrow)